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NOTE ON THE NECESSARY CONDITION THAT TWO LINEAR HOMOGENEOUS DIFFERENTIAL EQUATIONS SHALL HAVE COMMON INTEGRALS.*

By IDA MAY SCHOTTENFELS.

Professor Von Escherich in the *Denkschriften der Wiener Akademie*, Vol. 46, and later Heffter in *Crelle's Journal*, Vol. 116, proved that there exists for linear differential homogeneous equations a theory analogous to that of algebraic equations, confining their researches to the analogues to theorems upon the Highest Common Factor and Lowest Common Multiple.

During the past year Dr. Epstein and Dr. Pierce revived this subject, and in *THE AMERICAN MATHEMATICAL MONTHLY*, Vol. X, March, 1903, pp. 63-68, Dr. Epstein gives the necessary condition for one common integral, while Dr. Pierce gives the sufficient condition for $k \geq 1$ independent common integrals.

This note gives the necessary condition for two common integrals.

The following example illustrates the method.

$$(1) \quad a_0x^4 + a_1x^3 + a_2x^2 + a_3x + a_4 = 0,$$

$$(2) \quad b_0x^3 + b_1x^2 + b_2x + b_3 = 0.$$

To find the necessary condition that equations (1) and (2) have two roots in common. According to the well known dialytic method of elimination of Sylvester we may write

$$(3) \quad \begin{cases} a_0x^5 + a_1x^4 + a_2x^3 + a_3x^2 + a_4x = 0, \\ a_0x^4 + a_1x^3 + a_2x^2 + a_3x + a_4 = 0, \\ b_0x^5 + b_1x^4 + b_2x^3 + b_3x^2 = 0, \\ b_0x^4 + b_1x^3 + b_2x^2 + b_3x = 0, \\ b_0x^3 + b_1x^2 + b_2x + b_3 = 0. \end{cases}$$

Eliminating x^5, x^4, x^3, x^2 , from (3) we get

$$(4) \quad \begin{vmatrix} a_0 & a_1 & a_2 & a_3 & a_4x+0 \\ 0 & a_0 & a_1 & a_2 & a_3x+a_4 \\ b_0 & b_1 & b_2 & b_3 & 0x+0 \\ 0 & b_0 & b_1 & b_2 & b_3x+0 \\ 0 & 0 & 0 & b_1 & b_2x+b_3 \end{vmatrix} = 0.$$

Since (4) shall hold for at least two values of x , and yet is linear in x , it is an identity in x , and hence

* Presented to the American Mathematical Society (New York) October 30, 1903.

$$(5) \quad \begin{vmatrix} a_0 & a_1 & a_2 & a_3 & a_4 \\ 0 & a_0 & a_1 & a_2 & a_3 \\ b_0 & b_1 & b_2 & b_3 & 0 \\ 0 & b_0 & b_1 & b_2 & b_3 \\ 0 & 0 & 0 & b_1 & b_2 \end{vmatrix} \equiv 0, \quad \begin{vmatrix} a_0 & a_1 & a_2 & a_3 & 0 \\ 0 & a_0 & a_1 & a_2 & a_4 \\ b_0 & b_1 & b_2 & b_3 & 0 \\ 0 & b_0 & b_1 & b_2 & 0 \\ 0 & 0 & 0 & b_1 & b_3 \end{vmatrix} \equiv 0.$$

Hence the required necessary condition that equations (1) and (2) have two roots in common is the vanishing of determinants (5).

The generalization to equations of degree m and n , that have p roots in common follows readily. The equation of degree m must be multiplied by x^{n-p} while the one of degree n must be multiplied by x^{m-p} .

In exactly the same manner the analog of this method for linear homogeneous differential equations can be developed. The theorem that a linear homogeneous differential equation of the n th order has n and only n linearly independent integrals is employed, and the necessary condition is expressed in linear homogeneous differential operators, and has a form analogous to that of the necessary condition (5).

Given the following two linear homogeneous differential equations:

$$(I) \quad a_0(x)y^{iv} + a_1(x)y''' + a_2(x)y'' + a_3(x)y' + a_4(x)y = 0,$$

$$(II) \quad \beta_0(x)y''' + \beta_1(x)y'' + \beta_2(x)y' + \beta_3(x)y = 0.$$

If these two equations I and II have at least one common integral, we can by differentiation write,

$$(III) \quad \begin{cases} a_0 y^v + (a_0' + a_1) y^{iv} + (a_1' + a_2) y''' + (a_2' + a_3) y'' + (a_3' + a_4) y' + a_4' y \equiv 0 \\ \beta_0 y^v + (2\beta_0' + \beta_1) y^{iv} + (\beta_0'' + 2\beta_1' + \beta_2) y''' + (\beta_1'' + 2\beta_2' + \beta_3) y'' + (\beta_2'' + 2\beta_3') y' + \beta_3'' y \equiv 0 \\ \beta_0 y^{iv} + (\beta_0' + \beta_1) y''' + (\beta_1' + \beta_2) y'' + (\beta_2' + \beta_3) y' + \beta_3' y \equiv 0 \\ \beta_0 y''' + \beta_1 y'' + \beta_2 y' + \beta_3 y \equiv 0. \end{cases}$$

Eliminating y^v , y^{iv} , y''' , y'' from (III) we get

$$(IV) \quad \begin{vmatrix} a_0 & a_0' + a_1 & a_1' + a_2 & a_2' + a_3 & (a_3' + a_4)y' + a_4' y \\ 0 & a_0 & a_1 & a_2 & a_3 y' + a_4 y \\ \beta_0 & 2\beta_0' + \beta_1 & \beta_0'' + 2\beta_1' + \beta_2 & \beta_1'' + 2\beta_2' + \beta_3 & (\beta_2'' + 2\beta_3') y' + \beta_3'' y \\ 0 & \beta_0 & \beta_0' + \beta_1 & \beta_1' + \beta_2 & (\beta_2' + \beta_3) y' + \beta_3' y \\ 0 & 0 & \beta_0 & \beta_2 & \beta_2 y' + \beta_3 y \end{vmatrix} \equiv 0$$

which may be written $\lambda y' + \mu y = 0$.

If there are two independent common integrals, IV must hold for two linearly independent functions y (one not a constant times the other), whence $\lambda = 0$, $\mu = 0$, or

$$(V_1) \begin{vmatrix} a_0 & a_0' + a_1 & a_1' + a_2 & a_2' + a_3 & a_3' + a_4 \\ 0 & a_0 & a_1 & a_2 & a_3 \\ \beta_0 & 2\beta_0' + \beta_1 & \beta_0'' + 2\beta_1' + \beta_2 & \beta_1'' + 2\beta_2' + \beta_3 & \beta_2'' + 2\beta_3' \\ 0 & \beta_0 & \beta_0' + \beta_1 & \beta_1' + \beta_2 & \beta_2' + \beta_3 \\ 0 & 0 & \beta_0 & \beta_1 & \beta_2 \end{vmatrix} \equiv 0,$$

$$(V_2) \begin{vmatrix} a_0 & a_0' + a_1 & a_1' + a_2 & a_2' + a_3 & a_4' \\ 0 & a_0 & a_1 & a_2 & a_3 \\ \beta_0 & 2\beta_0' + \beta_1 & \beta_0'' + 2\beta_1' + \beta_2 & \beta_1'' + 2\beta_2' + \beta_3 & \beta_3'' \\ 0 & \beta_0 & \beta_0' + \beta_1 & \beta_1' + \beta_2 & \beta_3' \\ 0 & 0 & \beta_0 & \beta_1 & \beta_3 \end{vmatrix} \equiv 0.$$

Hence V_1 and V_2 furnish the required necessary condition.

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LINEAR COVARIANTS OF THE BINARY QUADRATIC AND CUBIC.

By L. C. WALKER, Professor of Mathematics, Colorado School of Mines, Golden, Col.

The definition of *weight* is that every coefficient is of weight w measured by its suffix, and that every product of coefficients is of weight measured by the sum of the suffixes of its various factors.

A semi-covariant of the two quantities is a function of the two sets of coefficients, which is homogeneous in each set separately, and *isobaric* (equal weight) on the whole, though not necessarily in the sets separately.

The practice of speaking of a covariant whose dimensions are partial degrees i_1, i_2 in the two sets of coefficients and ω in the variables has of late become almost universal.*

The degrees of quantities in the variables are generally† spoken of as their orders p_1, p_2 .

The order ω , the partial degrees i_1, i_2 in the coefficients of the binary quadratic and cubic

$$(a_0, a_1, a_2)(x, y)^2, \quad (b_0, b_1, b_2, b_3)(x, y)^3,$$

and the weight w of the semi-invariant which is the leading coefficient C_0 in the linear covariant, are connected by the relation $i_1 p_1 + i_2 p_2 - \omega = 2w$.

Here $p_1 = 2, p_2 = 3, \omega = 1$, whence $2i_1 + 3i_2 - 1 = 2w$. More generally, if m be any positive integer and n any positive odd integer, we have, from the conditions of linear covariancy, $2mi_1 + 3ni_2 - 1 = 2w$. Thus the binary quadratic and cubic have an indefinite number of linear covariants.

*Elliott's *Algebra of Quantics*. †*Ibid*.